A REVIEW ON THE TRIBOLOGICAL CHARACTERISTICS OF CO-DEPOSITED NICKEL WITH NANO / MICRO SIC METAL MATRIX COMPOSITE COATINGS ON ALUMINIUM 7075

PRADEEP DEVANEYAN. S[1] & T. SENTHILVELAN[2]

[1]Associate Professor, Department of Mechanical Engineering, Christ College of Engineering and Technology, Pitchaveeranpet, Moolakulam, Puducherry, India

[2]Professor, Department of Mechanical Engineering, Pondicherry Engineering College, Pillaichavadi, Puducherry, India

ABSTRACT

In this review, mechanical properties such as wear resistance, hardness, scratch resistance of electrocodeposited Nickel with micro and nano SiC on Aluminium 7075 are discussed. Electro codeposition of MMC coating have been influenced by many factors viz., current density, voltage, percentage of particle concentration, addition of surfactant and bath composition are also conferred. Elaborate review has been dispensed on these factors to find the optimum parameters. The state of art has been discussed with the support of literatures.

KEYWORDS: Electro-Codeposition, Nano and Micro SiC, Tribology, Aluminium 7075

INTRODUCTION

The inherent lightness and good strength-to-weight ratio of aluminium 7075 has focused attention on increasing applications in aerospace and allied fields. Since its density is one third of the steel, it replaces many metals in applications where weight is considered as a major factor. As one of the important application, Aluminium 7075 is employed in aerospace structural fastened joints where fretting wear and fretting fatigue damages can cause catastrophic failures under fluctuating loads [1-5]. Some aluminum 7075 based parts, such as engine pistons, working under fairly high temperatures and wearing conditions should surface treated to increase the wear resistance and to lower the coefficient of friction. Considerable interest on electrodepostion of nickel on aluminum 7075 has increased substantially due to the fact that the coating can eradicate the disadvantages of uncoated aluminum to some extent [3-7].

Metal matrix Composite coating by electro deposition is a process of co depositing fine particles of micro and nano size metallic, non metallic materials along plating to enhance material properties such as wear resistance, lubrication, corrosion resistance [6-10]. Hardness enhancement, good wear and corrosion resistance will get elevated higher in electroplated metals or alloys when compared to pure metal or alloy [11-15]. Electroplating finds wide range of applications in engine cylinders, high pressure valves, drill fittings, aerospace, micro electro mechanical systems, medical devices, marine, mining and nuclear fields [16-20]. In the current scenario, research on electro deposition of nano and micro composite coatings require optimization of the parameters such as current density, voltage, temperature, percentage of particle concentration and bath composition.

The literature survey reveals the fact that the ceramic particles such as SiC, Al_2O_3, Cr_2O_3, TiO_2, MoS_2, WC, and ZrO_2 nickel plating improves the wear resistance of the plated component [6-20]. The codeposition of nano sized

particles in Metal Matrix Composite coatings is more difficult and complex process than the micro sized particles [23]. The nano particles have a higher tendency to agglomerate which leads to heterogeneity in the deposit. Hence it is detrimental to the mechanical properties of the deposit [24]. To attain the homogenous distribution of nano particles in the electro deposition, embedding the particle in near non agglomerated form needs more attention for research which leads to harder and more corrosion resistant coatings.

Commercially, Direct Current was employed to coat nickel using nickel sulphate bath but fewer researches have made attempts to find the influence of pulse current on electro codeposition [25]. A comprehensive review of the current and potential applications of Direct current and Pulse Current on electro codeposition of nickel with nano or micro sized SiC particles to attain optimized properties have been provided in this paper through the reviews of literatures.

MATERIALS AND METHODS

The Electrolyte

The standard Watt's nickel sulphate solution was used for plating. The composition of the plating solution and the parameters are given in Table 1. Many researches carried out with the common chemical composition of the Watt's bath. The surfactants such as tetra Methyl Ammonium Hydroxide (TMAH), Sodium Dodecyl Sulphate were added to avoid the agglomeration of the micro and nano particles which have to be codeposited on the MMC coatings [26, 27]. In addition to the surfactants, stirring at constant speed using either mechanical, magnetic and ultrasonic stirrers were used to maintain the homogeneity of the dispersed micro or nano particles. Literatures reveals that even the stirring speed either mechanical or by ultrasonic method has the effect on the particle codeposition in the MMC coatings [28]. The bath has to be stirred for minimum of one hour using stirrer before the coating in order to avoid the particles to get agglomerated at the bottom of the bath. The electrodeposition can be carried out using two techniques shown in figure 1 a and b. One of which named as conventional Electro-co-deposition Technique (CECD) in which the electrodes are positioned vertically in the bath or by Sediment Electro-co-deposition (SECD) in which electrodes are positioned horizontally one over the other with sufficient inter-electrode distance so that the particle settle on the electrode surface as sediment on the cathode as the metal deposition progresses [29]. The results of the SECD depicts that it yields higher volume percentage incorporation of particles in the deposit rather than CECD.

Table 1: Chemical Composition of the Bath and the Parameters of Electrodeposition

Compositions and Conditions	
Electrolyte (Watts' Type)	**Concentration (gL^{-1})**
$NiSO_4.6H_2O$	300
$NiCl_2.6H_2O$	50
H_3BO_3	40
Sodium Dodecyl sulphate	0.2
Silicon Carbide (SiC)	5, 10, 15, 20
pH	4
Temperature (^{o}C)	55
Current Density (A/dm^2)	0.5-2
Stirring Speed (rpm)	250 -650
Plating Time (min)	60

SiC Particle Preparation

Both micro and nano sized SiC particles have the tendency to get agglomerated in the electrolyte and also in codeposition process. Hence the particles were blended with little electrolyte and required volume of surfactant was also

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added to make it in the form of paste. And it was added in the plating bath with the required volume and treated ultrasonically for 15 -20 minutes besides stirring with the speed of 200 – 300 rpm using mechanical or magnetic stirrer for a minimum of 30 -60 minutes before deposition [30].
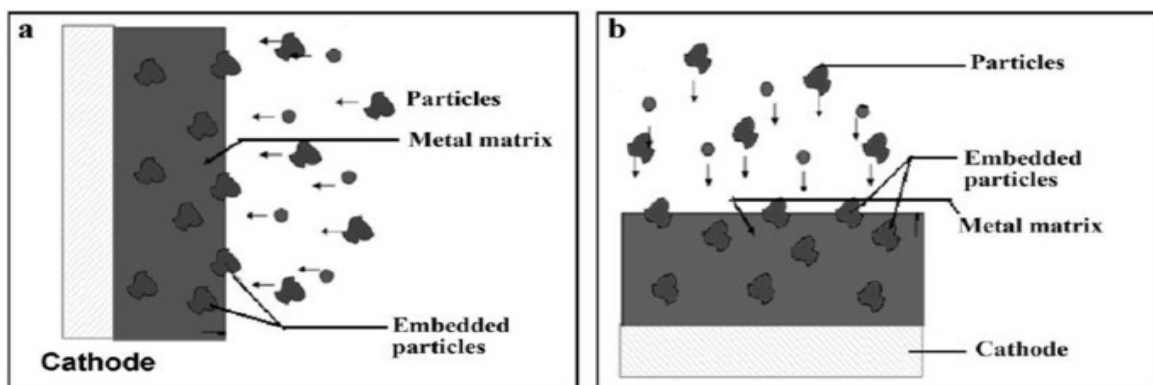

Figure 1: Schematic of the Co Deposition Techniques a: CECD and b: SECD [29]

Preparation of the Substrate

Electrodeposition of nickel on aluminium substrate cannot be carried out directly since the aluminium substrate will not have the tendency to get coated with nickel deposition. Hence the substrate travels a long procedure till it has been codeposited with Nickel along with the micro or nano particles. Aluminium 7075 rods were machined to billets of size 25 mm height and 25 mm diameter as per the ASTM standards. Then they were polished with SiC sandpaper till 2000 grit size to obtain uniform and smooth surface. Prior to electroplating, for removal of natural oxide film, Aluminium substrate were first degreased in 42 g/L NaOH solution at 65°C for 20 seconds. They were rinsed with distilled water and dipped in zincate bath (Zinc oxide 100 g/L, Sodium hydroxide 525 g/L, ferric chloride 10 g/L and Sodium tartrate 1 g/L) for 30 seconds and cleaned with distilled water. Further the zincated substrate was dipped in copper sulphate bath for copper deposit for 20 seconds and again washed in distilled water before the codeposition of Ni- micro/Nano SiC was done [31].

Plating Details

The nickel plate of 99.9 % purity has been used as anode and it has to be cleaned properly to remove the natural oxides. Microcontroller has to be developed to perform the test for both Direct Current (D.C.) and Pulse Current (P.C.) in which potentiometer has to be used for D.C. and rectifier has to be used for P.C. The bath was controlled by this microcontroller through which the current density, voltage, temperatures, coating time and stirring speed were controlled. The duty cycle for the Pulse Current can also be controlled by this microcontroller. Various input and output devices have to be connected to the microcontroller by which parameters can be edited and monitored. The schematic representation of the plating bath with the microcontroller is shown in figure 2. The fresh electrolyte has to be taken for each set of plating. The micro or nano SiC particles have to be dispersed for the required amount and it has to be homogenously mixed using stirrer before plating.

Deposit Testing Methods

Codeposition of SiC particles along with the Nickel were ascertained by using Scanning Electron Microscope (SEM) together with Energy Dispersive X-ray (EDX). SEM reveals the SiC particle codeposition and showcase the agglomeration if present in the plating. The results of EDX can be transformed to % of weight and volume of SiC using a

density value of 3.2 g/cm^3 for SiC [29]. High resolution Transmission Electron Microscope (TEM) can be utilized after preparing the sample by peeling off the coating from the substrate and a foil of required diameter has to be obtained, then polished for thinning to do analysis. Cross sectional analysis of the composite coating can be made by mounting the specimen in the araldite baking, sectioning the specimen, metallographic polishing, etching and then examining by SEM [32]. The hardness of the coating can be measured using a Vicker's microhardness intender [33]. To determine the Phase present and to find the preferred orientation of the deposit, X-Ray Diffraction (XRD) can be adopted [34]. Tribological performance of the coating can be studied using either pin-on-disc or ball-on-disc tribo-tester. The dynamic coefficient of friction can be recorded continuously during sliding test, while the wear coefficient can be determined by Archard's equation, $K = VH/LS$, where V is the volume loss of material, H is the hardness, L is the applied load and S is the total sliding distance. The volumetric wear loss V can be determined using the equation $V = \pi h^2[r-h/3]$, where r is the radius of hemispherical pin and h in=s the wear height loss of the pin [35]. All friction and wear test has to be performed under unlubricated condition at room temperature and in ambient air with relative humidity 48-52%. The composite coating can be tested for wear and adhesion failure by also adopting scratch tester consisting of a specimen stage and a stylus with a diamond tip. The scratch tester has a built in camera to view and capture the scratch images and a graphical display of forces to indicate scratch failure [23].
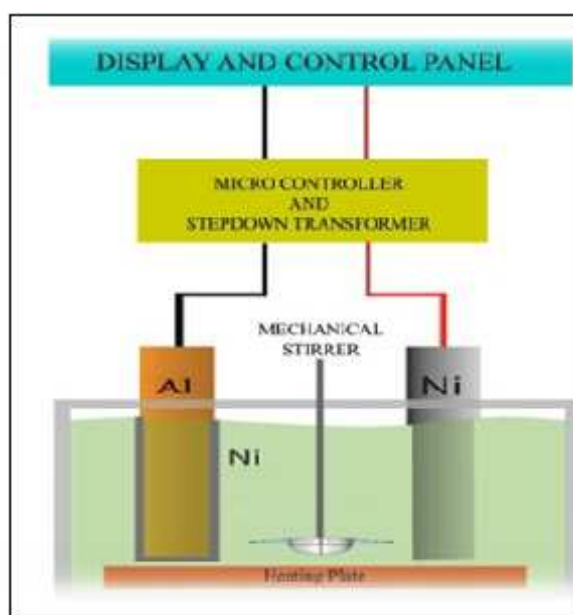

Figure 2: Schematic Diagram of the Experimental Setup

EFFECTS OF PARAMETERS AND DISCUSSION OF RESULTS

Effects of Current Density

The codeposition of micro and nano SiC particles has correlation with the current density. The volume fraction of SiC particle in the coating increases linearly till a peak value of current density and further then, it decreases rapidly. This occurs due to the faster movement of metal ions towards the cathode than the adsorbed nano / micro SiC particles [26]. In composite electrodeposits, the actual current density is considerably higher than the apparent current density since the SiC particles occupy the sites available for nickel deposition [29]. Hence the moderate low current density is preferable to obtain homogenous deposits. The time required to obtain the required thickness is more in low current density when compared with high current density. Not only the inclusion of SiC particles is lower with higher current density, the deposit

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also become brittle and powdery due to concentration of polarity [29]. But high current density is given, the thickness of the coating also increases linearly which will lead to higher microhardness and least wear depth [37]. Every substrate that are been coated has an optimum value of current density which depends on the volume of the substrate and the bath volume. Beyond the optimum current density, the coating loses its wear resistance.

Effects of % Volume of SiC

The influence of SiC content in the plating bath on the deposition rate and the codeposition of SiC are discussed in this topic. With the increase in SiC content in plating bath the deposition rate and codeposition increase linearly and reach a maximum value and it decreases with the further increase in SiC content [32]. An ionic cloud around SiC particles are formed because of the adsorption of nickel ions on the SiC particle surfaces. This ionic cloud size decides the deposition rate, i.e. more the size higher the deposition rate. However, when the SiC content exceeds the optimum value, the suspended SiC particles agglomerated in the plating bath and also on the codeposited MMC coatings [38]. Agglomeration in the plating bath restricts the addition of SiC particles in the Nickel matrix. When the particle density is higher, the elastic collision of the SiC particles inside the electrolyte leads to the backscattering from the interface between electrolyte and the substrate [38]. The entrapment of SiC particles between the Ni matrix can happen only when the it clung to the cathode surface for sufficient period. This can happen only when the rate of deposition of nickel and SiC particle is higher. The tribological properties of SiC codeposited on the Ni matrix are higher than the deposition of pure nickel on Aluminium 7075. The micro hardness of the nickel is elevated to higher value when the % of SiC codeposition increases which decreases the wear depth [37].

Effects of Pulse Current

Recent studies on pulse current clearly depict the fact that higher gravimetric incorporation percentage of micro and nano SiC particles in nickel matrix can be attained in Pulse Current when compared to Direct Current. During DC deposition, the constant current density is adopted for codeposition of metal and SiC particles. Since the particle transfer is always slower than the metal ions which lead to decrease of the concentration of the adsorbed particles at the cathodic surface, the adsorption become weak. However, in Pulse Current, during the off time the micro and nano SiC particles can be supplied when the Current Density is low or zero, which results in the enhanced amount of SiC particles in the coating. Thus the efficiency of the particle transfer in Pulse Current is higher than Direct Current [37]. Figure 3 clearly shows the gravimetric percentage of micro and nano SiC embedded in nickel matrix prepared under both Direct Current and Pulse Current [39]. Embedding of micro and nano size SiC particles is higher during 10% duty cycle and the % SiC becomes lower when the duty cycle is increased gradually from 10% to 50%. The behaviour of coating is difficult for both micro and nano SiC particles. The micro SiC particle addition is higher at 10% duty cycle and it gradually reduces when the duty cycle has been increased to 90%, but the percentage of incorporation is always higher than Direct Current coating. Whereas in nano SiC coatings percentage of incorporation is higher than Direct Current at 10% duty cycle but when further increasing of duty cycle, the codeposition percentage rapidly decreases below the percentage of Direct Current codeposition [39]. This occurs due to the fact that micro sized particles are codeposited as inter-crystalline mechanism at the borders and the edges of nickel crystallites, whereas nano sized particles are incorporated as intra-crystalline mechanism inside the nickel crystals.
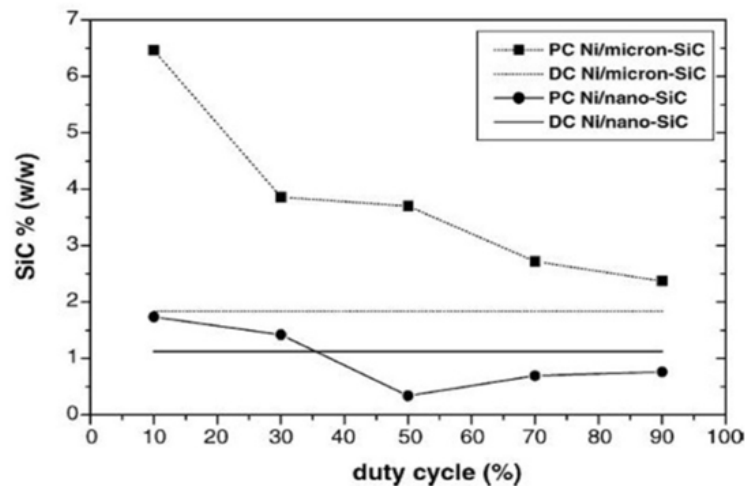
Figure 3: Gravimetric Percentage of Embedded Micro and Nano SiC Particles in Composite Ni/Sic Deposits Prepared under Direct and Pulse Current Plating Conditions and Various Duty Cycle [39]

Effects of Stirring Speed

During the electro-codeposition, the SiC particles have a strong tendency to settle to the bottom of the plating bath [32]. Also the suspending particles in plating bath has a tendency to agglomerate, these problems can be avoided by stirring the plating bath by utilizing mechanical, magnetic and ultrasonic stirrer. The studies related to this field emphasis that the deposition rate increases with increasing stirring speed up to an optimum level. Further increase in stirring speed decreases the deposition rate [32]. Figure 4 depicts the relationship between the stirring rate and the percentage of codeposited SiC in coating [26]. The deposition rate increases with increasing stirring speed and shows a maximum deposition and then decreases when further increase in stirring speed. Srivastava. et. al [35] stated that there is no significant effect of stirring speed in low percentage load of SiC. However, at higher percentage of load of SiC, there is a significant increase in microhardness when the stirring speed increases. This phenomenon clarifies the fact that the significant role of stirring speed in codeposition of SiC in nickel matrix. As stated earlier, increase in SiC incorporation in MMC coating leads to the increase in microhardness of the plated substrate [38]. It is also evident that to attain a homogeneous distribution of SiC in plating, it is necessary to apply stirrer. Hence the stirrer not only improves the codeposition but also enhances the homogeneity of the SiC distribution.
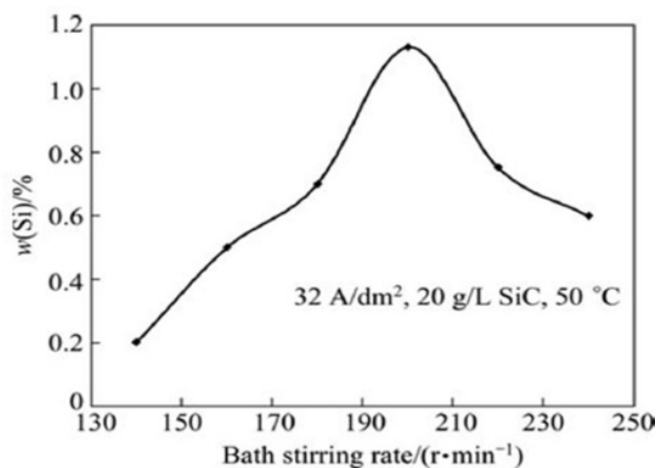

Figure 4: Mass Fraction of Sic in Coating vs Plating Bath Stirring Rate[26]

Effects of Surfactants

It has been reported by many researchers that the codeposition of nano SiC particles smaller than 100nm is more difficult than 0.8 µm size micro particles [29]. The literatures reveal the fact that increasing the concentration of the surfactant increases the SiC particles zeta potential. Zeta potential can also be increased by adding surfactant which improvises adsorption of cationic action. The increase in surfactant can activate the positive zeta potential which offers the extra adhesion force between the inert particles like SiC and the cathode substrate as shown in figure 5. It is also shown in figure 6 that the volume fraction of the codeposited SiC can be increased by increasing the concentration of surfactant [28].Various surfactants are added in different percentages to attain the reduction of agglomeration of particles in the bath. For a bath containing 5 g/l of SiC particles, the volume percentage increases from 8 to 22% for nano sized particle and from 10 to 29 % for micro sized particle due to the addition of surfactant.
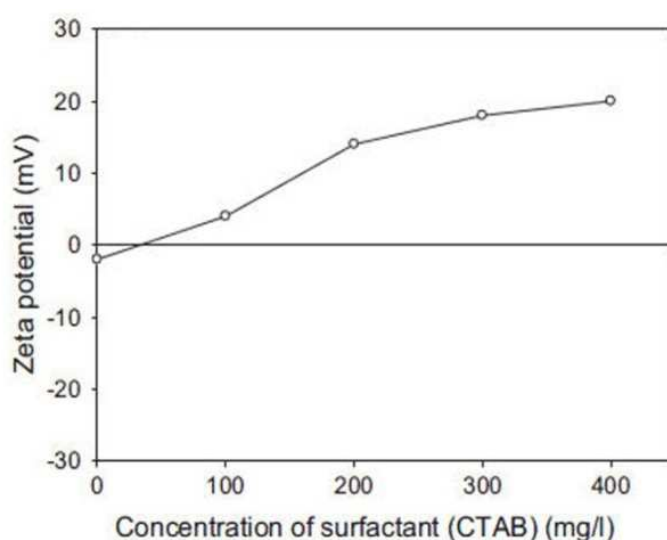

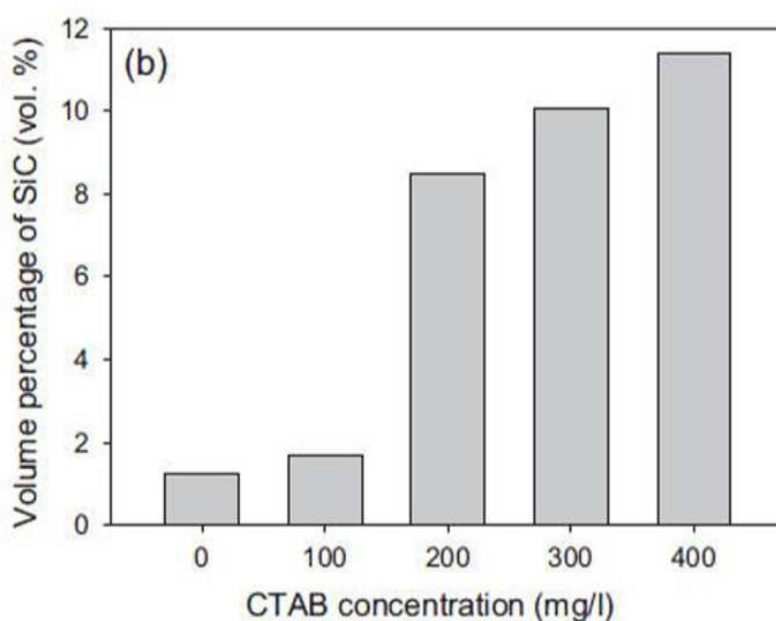**Figure 5: Surfactant Concentration and Zeta Potential Relationship[28]**

Figure 6: Volume Percentage of Codeposited SiC Particles for Various Surfactant Concentrations[28]

CONCLUSIONS

The aim of this review is to throw spotlight on the parameters like current density, voltage, temperature, percentage of particle concentration, addition of surfactant and bath composition that affect the electro-codeposition of nickel with micro and nano SiC particles on Aluminium 7075. Throughout the review it is predominant that incorporation of SiC particles enhances the wear, scratch, microhardness and corrosion properties of the nickel coating. The microstructure study reports that the codeposition of SiC with nickel refines the grain size, thus increases the tribological properties. Hence the controlling of process parameters to the optimum level worth sure enough in increasing the coating life to the maximum period.

REFERENCES

1. Anabela Gomes, Isabel Pereira, Beatriz Fernandez, Rosario Pereiro, Electro-deposition of metal matrix nanocomposites: improvement of the chemical characterization techniques, in: Boreddy Reddy (Ed.), Advances in Nanocomposites- Synthesis, Characterization and Industrial Applications, In Tech., 2011, p503.

2. A. Hovestad, L. J. J. Jansen, Electroplating of metal matrix composites by codeposition of suspended particles, in: B. E. Convey (Ed.), Modern Aspects of Electrochemistry, Kluwer Academic/ Plenum Publishers, Newyork, 2005, Number 38.

3. C. T. J. Low, R.G.A. Wills, F. C. Walsh, Electrodeposition of composite coatings containing nano particles in a metal deposit, Surface Coating Technology 201 (2006) 371- 383.

4. R. Hovestad, L. J. J Jansen, Electrochemical codeposition of inert particles in a metallic matrix, Journal of Applied Electrochemistry 25 (1995) 519 – 527.

5. J. L. Stojak, J. Fransaer, J.B. Talbot, Review of electrocodeposition, in: R. C. Alkire, D. M. Kolb (Eds.), Advances in Electrochemical Science and Engineering, 7, Wiley VCH Verlag-GmbH, 2001, p193.

6. M. R. Vaezi, S. K. Sadrnezhaad, L. Nikzad, Electrodeposition of Ni-SiC nano composite coatings and evaluation of wear and corrosion resistance and electroplating characteristics, Colloid Surf. A: Phusicochem. Eng. Aspects 315 (2008), 176-182.

7. S. T. Aruna, V. K. William Grips, K. S. Rajam, Ni based electrodeposited composite coating exhibiting improved microhardness, corrosion and wear resistance properties, J. Alloys Compd., in press.

8. K. H. Hou, M.D. Ger, L. M. Wang, S.T ke, The wear behavior of electro-codeposited Ni-SiC composites, Wear 253 (2002) 994-1003.

9. S.C. Wang, W.C.J. Wei, Kinetics of electroplating process of nano- sized ceramic particle/ Ni composite, Mater. Chem. Phys. 78 (2003) 574-580.

10. L. Chen, L. Wang, Z. Zeng, J. Zhang, Effect of surfactant on the electrodeposition and wear resistance of Ni-Al$_2$O$_3$ composite coatings, Mater. Sci. Eng. A 434 (2006) 319-325.

11. L. Wang, Y. Gao, H. Liu, q. Xue, T. Xu, Effects of bivalent Co ion on the co-deposition of nickel and nano –diamond particles, Sur. Coat. Technol. 191 (2005) 1-6.

A Review on the Tribological Characteristics of Co-Deposited Nickel with Nano / Micro
SiC Metal Matrix Composite Coatings on Aluminium 7075

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12. L. Chen, L. Wang, Z. Zeng, T. Xu, Influence of pulse frequency on the microstructure and wear resistance of electrodeposited Ni-Al$_2$O$_3$ composite coatings, Surf. Coat. Technol. 201 (2006) 599-605.

13. N. K. Shrestha, T. Takebe, T. Saji, Effect of particle size on the co-deposition of diamond with nickel in presence of a redox-active surfactant and mechanical property of the coatings, Diamond Relt. Mater. 15 (2006) 1570- 1575.

14. D. J. Riley, Electrochemistry in nano particle science, Curr. Opin. Colloid Interface Sci. 7 (2002) 186-192.

15. M. Surender, b. Basu, R. Balasubramainiam, Wear characterization of electrodeposited Ni-WC composite coatings, Tribology Int. 37 (2004) 743-749.

16. B. Szczgiel, M. Kolodziej, Composite Ni/Al$_2$O$_3$ coatings and their corrosion resistance, Electrochim. Acta 50 (2005) 4188-4195.

17. T. Lamke, B. Wielage, D. Dietrich, A. Leopold, Details of crystalline growth in co-deposited electroplated nickel films with hard (nano) particles, Appl. Surf. Sci. 253 (2006) 2399-2408.

18. M. D. Ger, Electrochemical deposition of nickel/ SiC composites in the presence of surfactants, Mater. Chem. Phys.87 (2004) 67-74.

19. F. Hu, K.C. Chan, Equivalent circuit modeling of Ni-SiC electrodeposition under ramp-up and ramp-down waveforms, Mater. Chem. Phys. 99 (2006) 424-430.

20. A. Abdel Aal, Z. I. Zaki, Z. Abdel Hamid, Novel composite coatings containing (TiC- Al2O3) powder, Mater. Sci. Eng. A 447 (2007) 87-94.

21. N. Periene, A. Cesuniene, L. Taicas, electroplating of metal matrix nanocomposites: improvement of the chemical characterization techniques, Plat. Surf. Finish. 10(1993) 73.

22. R. H. Oskouei, R.N. Ibrahim, M. R. Barati, An experimental study on the characteristics and delamination of TiN coatings deposited on Al 7075-T6 under fatigue cycling, Thin Solid Fiilms, 526, (2012), 155-162.

23. P. Narasimman, Malathy Pushpavanam, V. M. Periasamy, Wear and scratch resistance characteristics of electrodeposited nickel-nano and micro SiC composites, Wear, 292-293, (2012) 197-206.

24. G. Zaklina, B. Dusan, M. Mirjana, The influence of SiC particles on the compressive properties of metal matrix composites, Materials Characterization,47, (2001), 129-138.

25. Thiemig Denny, lange Ronny, Bund Andreas, Influence of pulse plating parameters on the electrocodeposition of matrix metal nanocomposites, Electrochimica, (2007), 52,7362- 7371.

26. M. Arab JUNEGHANI, M. Farzam, H. Zohdirad, Wear and corrosion resistance and electroplating characteristics of electrodeposited Cr-SiC nano composites coatings, Trans. Nonferrous Met. Soc. China 23 (2013), 1993-2001.

27. S. Mohajeri, A. Dolati, S. Rezagholibeiki, Electrodeposition of Ni/WC nano composite in sulfate solution, Mat. Che. Phys. 129, (2011), 746- 750.

28. F. Kilic, H. Gul, S. Aslan, A. Alp, H. Akbulut, Effect of CTAB concentration in the electrolyte on the Tribological properties of nanoparticle SiC reinforced Ni metal matrix composite (MMC) coatings produced by electrodeposition, Colliods and Surfaces A: Physicochem. Eng. Aspects 419, (2013), 53-60.

29. P. Narasimman, Malathy Pushpavanam, V.M. Peiasamy, Synthesis, characterization and comparison of sediment electro-codeposited nickel-micro and nano SiC composites, Applied Surface Science 258, (2011), 590-598.

30. Gajendra Sharma, R.K. Yadava, V.K. Sharma, Characteristics of electrocodeposited Ni-Co-SiC composite coating, Bull. Mater. Sci., Vol. 29, No. 5, Oct. 2006, p.p. 491-496.

31. S. M. Lari Bagal, M. Heydarzadeh, Soli, A. Amadeh, A functionally gradient nano-Ni-Co/SiC composite coating on aluminum and its Tribological properties, Surface and coatings Technology, 206, (2012), 4032-4039.

32. Hong-Kee Lee, Ho-Young Lee, Jun-Mi Jeon, Codeposition of micro and nano –sized SiC particles in the nickel matrix composite coatings obtained by electroplating, Surface and coating technology, 201, (2007), 4711-4717.

33. Yanqiu xia, Shina sasaki, Takashi Murakami, Miki Nakano, Lei Shi, Haizhong Wang, Ionic liquid lubrication of electrodeposited nickel- Si_3N_4 composite coatings, Wear, 262, (2007), 765-771.

34. M.R. Vaezi, S.K. Sadrnezhaad, L. Nikzad, Electrodeposition of Ni-SiC nano composite coatings and evaluation of wear and corrosion resistance and electroplating characteristics, Colloids and surfaces A: physicochem. Eng. Aspects, 315, (2008), 176- 182.

35. Meenu Srivastava, V. k. Willaim Grips, K.S. Rajam, Electrochemical deposition and Tribological behavior of Ni and Ni-Co metal matrix composites with SiC nano-praticles, Applied Surface Science, 253, (2007), 3814-3824.

36. Lei Shi, Chufeng Sun, Ping Gao, Feng Zhou, Weimin Liu, Mechanical properties and wear and corrosion resistance of electrodeposited Ni- Co/SiC nanocomposite coating, Applied Surface Science, 252, (2006) 3591-3599.

37. Y. Yang, Y. F. Cheng, Electrolytic deposition of Ni-Co-SiC nano-coating for erosion-enhanced corrosion of carbon steel pipes in oils and slurry, Surface and coatings technology, 205, (2011), 3198-3204.

38. H. Gul, F. Kilic, M. Uysal, S. Aslan, A. Alp, H. Akbulut, Effect of particle concentration on the structure and Tribological properties of submicron particle SiC reinforced Ni metal matrix composite (MMC) coatings produced by electrodeposition, Applied Surface Science, 258, (2012), 4260-4267.

39. P. Gyftou, M. Stoumbouli, E. A. Pavalou, P. Asimidis, N. Spyrellis, Triboligical study of Ni matrix composite coatings containing nano and micro SiC particles, Electrochimica Acto, 50, (2005), 4544-4550.